Developmental dyslexia in a computational model of reading.

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Recent work modeling dyslexia with computer simulations has begun to shed new light on the cognitive consequences of stroke and other forms of brain injury and dysfunction (Hinton & Shallice, 1991; Patterson, Seidenberg, & McClelland, 1989; Plaut & Shallice, 1993; Seidenberg, 1992). These investigations have, however, been limited to the consideration of acquired dyslexias simulated through training and subsequent "lesioning" of the computational model. While this kind of modeling may help explain disabilities with specific organic etiologies, this approach does little or nothing to help us understand the origins of developmental dyslexias which cannot be localized yet which account for a much larger percentage of children with severe reading difficulties in school settings. The purpose of this paper is to explore the explanatory power of a computational model in accounting for specifically developmental dyslexias.

The work described in this paper is framed within a broader research program that integrates traditional rule-based cognition with connectionist processing through a loosely coupled system of modules like that pictured in Figure 1. A central premise of the model is that both symbolic and connectionist processes are available at all stages of word reading and that word reading ultimately involves a balance between (at least) two different processing systems that employ radically different forms of orthographic knowledge. Although strategic decoding of words through grapheme-phoneme correspondence (GPC) rules is slow, in the earliest stages of reading acquisition GPC rules provide a more reliable approach than connectionist processing under conditions of limited experience. As the experience of a reader grows, however, the reliability of connectionist processing increases and the disadvantages of strategic rule-based processing become more important. These assumptions suggest that observed developmental trends in reading acquisition may be accounted for by a shift in dominance from primarily strategic rule-based cognition in early word reading, through a phase of mixed rule-based/connectionist processing, and finally into a primarily connectionist (automated) phase of mature word reading. These assumptions also suggest a possible model for developmental dyslexia.

The model of developmental dyslexia proposed is founded on the observation that beginning readers require many more exposures to new words than can normally be provided in direct instruction by teachers. A consequence of this is that beginning readers are frequently obliged to rely on self-generated feedback (Jorm & Share, 1983) through the use of context or decoding both of which are subject to error, particularly in the earliest stages of reading acquisition. The purpose of the simulation trials in this study is to explore the theoretical consequences of this kind of error-prone feedback on the long-term learning in a connectionist system like those that have recently been proposed as models of human cognition in reading (Seidenberg, 1992; Seidenberg & McClelland, 1989).

![Figure 1. Elements of the model.](image-url)
Method
A series of simulation studies were carried out training groups of networks under various conditions of error. Three different learning tasks were employed that varied in terms of task complexity. Task 1 was an auto-associative learning task that required reproduction of the input stimulus. Task 2 was a more complex learning task that simulated learning to read a corpus of 128 CVC words. Task 3 was a still more complex task that involved learning 128 CVC words with no predictable regularity in sound/symbol correspondence. All networks were adapted forms of C++ network and layer classes described by Rao and Rao (1993).

Results
Task 1 learning was carried out under two error conditions. One condition employed attenuated error, corresponding to simulated annealing where error is gradually reduced across training cycles. A second condition employed persistent error which was not reduced across cycles. Four levels of error were simulated. Data depicted in Figures 2 and 3, report the mean average error/pattern for each training cycle for all networks within pattern error levels.

As indicated in Figure 2, long-term learning under attenuated error is indistinguishable from learning under no error. No significant (p<.05) differences between levels of pattern error were revealed in one-way ANOVAs at cycle 100. Although error tends to induce occasional error peaks proportional to the current level of error, these peaks appear to be a result of the attenuation process since peaks tend to correspond with the error attenuation steps that occurred at cycles 10, 30, 50, and 70.

When error was persistent, however, long-term effects on learning were evident (See Figure 3). An ANOVA employing mean error at cycle 100 and level of persistent error as dependent and independent variables respectively revealed statistically significant group differences F(3,76)=4.4, p<.01. Follow-up Bonferroni tests indicated significant pair-wise differences between groups with error levels of 0.0 and 0.5.

Figure 2. Task 1 learning under attenuated error.

Figure 3. Task 1 learning under persistent error.

Figure 4. Task 2 CVC word learning under four conditions of persistent error.
Figure 4 depicts results of task 2 word learning under four levels of persistent error. A one-way ANOVA with error at cycle 20 revealed significant group differences, $F(3,60)=389.9$, $p < .0001$. Follow-up Bonferroni analyses indicated pair-wise differences between all pairs of groups except those with error levels of 0.3 and 0.5.

Results of Task 3 irregular word learning did not differ significantly from the outcomes observed in Task 2 suggesting that the increased demand of learning the randomized training data set was still well within the capacity of the network design.

Conclusions
A number of features of the simulation trials are of special interest from a cognitive modeling perspective. One feature, illustrated in Figure 2, is that even severe initial levels of error are quickly corrected as error is attenuated. In fact, error in the earliest stages of learning appears to dramatically enhance learning outcomes as evidenced by the significantly lower cycle 1 error scores in Figure 4. If, however, error persists undiminished, measurably lower learning outcomes result over extended periods of time and those deficiencies emerge at various points in the learning curve dependent upon the level of error in the system.

What this model suggests is that developmental dyslexia need not require either processing deficits or functionally distinct processes as has sometimes been suggested. Rather, these simulations suggest that the very same processes that enhance learning in its earliest stages may have significant negative effects in later stages of learning. The model also suggests an explanation for the critical role of phonological awareness and coding skills in early reading and the observation that dyslexic readers exhibit deficiencies in this area.

Finally, there is an intriguing interaction between the complexity of the task to be learned and the occurrence of measurably lower learning outcomes. It is not that complex tasks are more sensitive to error but rather that simpler tasks are subject to relatively greater within-group variation. This makes it more difficult to observe between-group differences and suggests one possible explanation for why the incidence of reading disability appears to be so much higher than that of other subject-specific difficulties (e.g., dyscalculia). It may be that the capacity to discern disabilities is related to the complexity of the task.

While this investigation does not answer specific empirical questions concerning the etiology of developmental dyslexias it does appear to offer a plausible, readily interpretable model that is consistent with recent empirical findings (Nicholson & Fawcett, 1989) suggesting that the concept of automaticity may play a central role in the learning difficulties characteristic of dyslexics. The more general framework upon which the present investigation is based also finds support in models of skill acquisition which are increasingly making use of encapsulated modules (Stanovich, 1990) and have frequently distinguished between strategic and automatic processing (Schneider & Fisk, 1983; Schiffren & Dumais, 1981; Sincoff & Sternberg, 1989).

References


